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A NOVEL METHOD FOR IRRIGATION SYSTEM USING SOLAR FED BLDC MOTOR

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Abstract:

ABSTRACT:
Objective- To design a simple cost effective and efficient method for a water supply system employing a brushless DC motor, fed with renewable source of energy(solar energy) from solar photovoltaic array and to obtain maximum power output from SPV array using maximum power point tracking(MPPT),employing zeta converter.
Design / Methodology/ Approach- Performance evaluation of proposed SPV array-fed BLDC motor-driven water pump employing a zeta converter is carried out using simulated results. The proposed system is designed, modeled, and simulated considering the random and instant variations in solar irradiance level and its suitability is demonstrated by testing the starting, steady state, and dynamic behaviour.
Findings- The SPV array-zeta converter-fed VSI–BLDC motor-pump has been proposed and its suitability has been demonstrated through simulated results and experimental validation.
Practical implications-We can implement this system in Rural area irrigation & fresh water pumping, Mini pump applications, BLDC application in robotics, Energy efficient mechanical machine operation.
Key words: zeta converter, VSI–BLDC, MPPT, SPV

I. INTRODUCTION

OVERVIEW

The drastic reduction in the cost of power electronic devices and annihilation of fossil fuels in near future invite to use the solar photovoltaic (SPV) generated electrical energy for various applications as far as possible. The water pumping, a standalone application of the SPV array-generated electricity, is receiving wide attention nowadays for irrigation in the fields, household applications, and industrial use. Although several researches have been carried out in an area of SPV array-fed water pumping, combining various dc–dc converters and motor drives, the zeta converter in association with a permanent magnet brushless dc (BLDC) motor is not explored precisely so far to develop such kind of system. However, the zeta converter has been used in some other SPV-based applications. Moreover, a topology of SPV array-fed BLDC motor-driven water pump with zeta converter has been reported and its significance has been presented more or less. Nonetheless, an experimental validation is missing and the absences of extensive literature review and comparison with the existing topologies have concealed the technical contribution and originality of the reported work. The merits of both BLDC motor and zeta converter can contribute to develop an SPV array-fed water pumping system possessing a potential of operating satisfactorily under dynamically changing atmospheric conditions. The BLDC motor has high reliability, high efficiency, high torque/inertia ratio, improved cooling, low radio frequency interference, and noise and requires practically no maintenance [5], [6]. On the other hand, a zeta converter exhibits the following advantages over the conventional buck, boost, buck–boost converters, and Cuk converter when employed in SPV-based applications.

1) Belonging to a family of buck–boost converters, the zeta converter may be operated either to increase or to decrease the output voltage. This property offers a boundless region for maximum power-point tracking (MPPT) of an SPV array. The MPPT can be performed with simple buck and boost converter if MPP occurs within prescribed limits.
2) This property also facilitates the soft starting of BLDC motor unlike a boost converter which habitually steps up the voltage level at its output, not ensuring soft starting.
3) Unlike a classical buck–boost converter, the zeta converter has a continuous output current. The output inductors make the current continuous and ripple free.
4) Although consisting of same number of components as a Cuk converter, the zeta converter operates as non-inverting buck–boost converter unlike an inverting buck–boost and Cuk converter. This property obviates a requirement of associated circuits for negative voltage sensing, and hence reduces the complexity and probability of slow down the system response.

These merits of the zeta converter are favorable for proposed SPV array-fed water pumping system. An incremental conductance maximum power point tracking (INC-MPPT) algorithm, is used to operate the zeta converter such that SPV array always operates at its MPP. The existing literature exploring SPV array-based BLDC motor-driven water pump is based on a configuration shown in Fig. 1. A dc–dc converter is used for MPPT of an SPV array as usual. Two phase currents are sensed along with Hall signals feedback for control of BLDC motor, resulting in an increased cost. The additional control scheme causes increased cost and complexity, which is required to control the speed of BLDC motor. Moreover, usually a voltage-source inverter (VSI) is operated with high-frequency PWM pulses, resulting in an increased switching loss and hence the reduced efficiency.

II. SYSTEM ANALYSIS

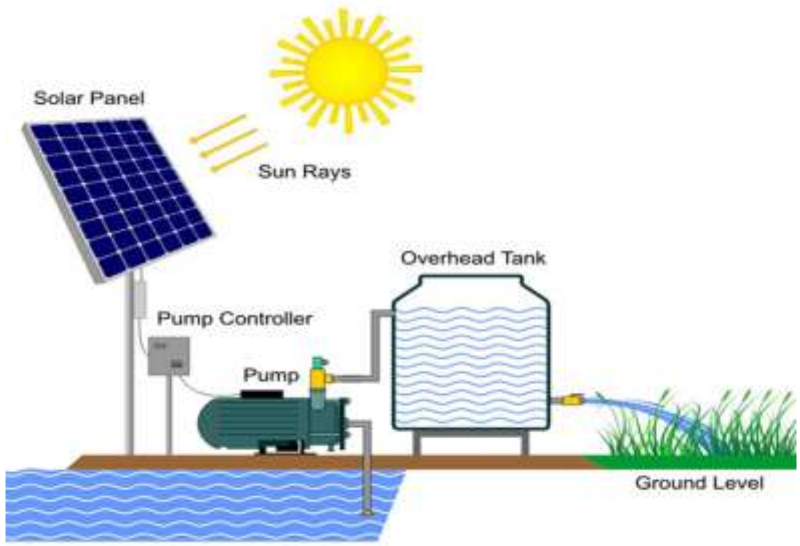
A solar-powered pump is a pump running on electricity generated by photovoltaic panels or the radiated thermal energy available from collected sunlight as opposed to grid electricity or diesel run water pumps. The operation of solar powered pumps is more economical mainly due to the lower operation and maintenance costs and has less environmental impact than pumps powered by an internal combustion engine (ICE). Solar pumps are useful where grid electricity is unavailable and alternative sources (in particular wind) do not provide sufficient energy.

The solar panels make up most (up to 80%) of the systems cost.[citation needed] The size of the PV-system is directly dependent on the size of the pump, the amount of water that is required (m^3/d) and the solar irradiance available.

The purpose of the controller is twofold. Firstly, it matches the output power that the pump receives with the input power available from the solar panels. Secondly, a controller usually provides a low voltage protection, whereby the system is switched off, if the voltage is too low or too high for the operating voltage range of the pump. This increases the lifetime of the pump thus reducing the need for maintenance.

Voltage of the solar pump motors can be AC (alternating current) or DC (direct current). Direct current motors are used for small to medium applications up to about 3 kW rating, and are suitable for applications such as garden fountains, landscaping, drinking water for livestock, or small irrigation projects. Since DC systems tend to have overall higher efficiency levels than AC pumps of a similar size, the costs are reduced as smaller solar panels can be used.

Finally, if an alternating current solar pump is used, an inverter is necessary that changes the direct current from the solar panels into alternating current for the pump. The supported power range of inverters extends from 0.15 to 55 kW and can be used for larger irrigation systems. However, the panel and inverters must be sized accordingly to accommodate the inrush characteristic of an AC motor.



III. SYSTEM DESIGN AND IMPLEMENTATION

BLOCK DIAGRAM

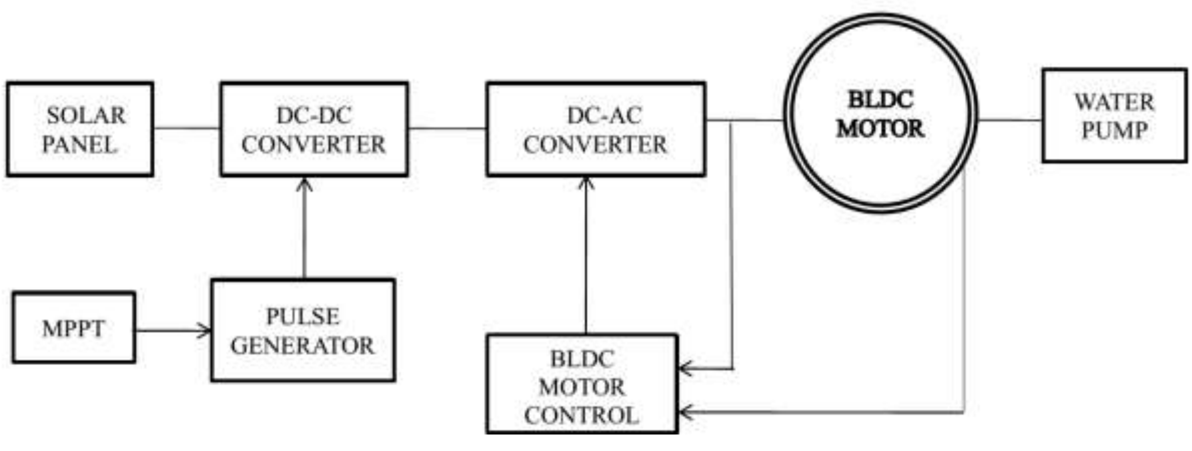


Fig. 1. Conventional SPV-fed BLDC motor-driven water pumping system

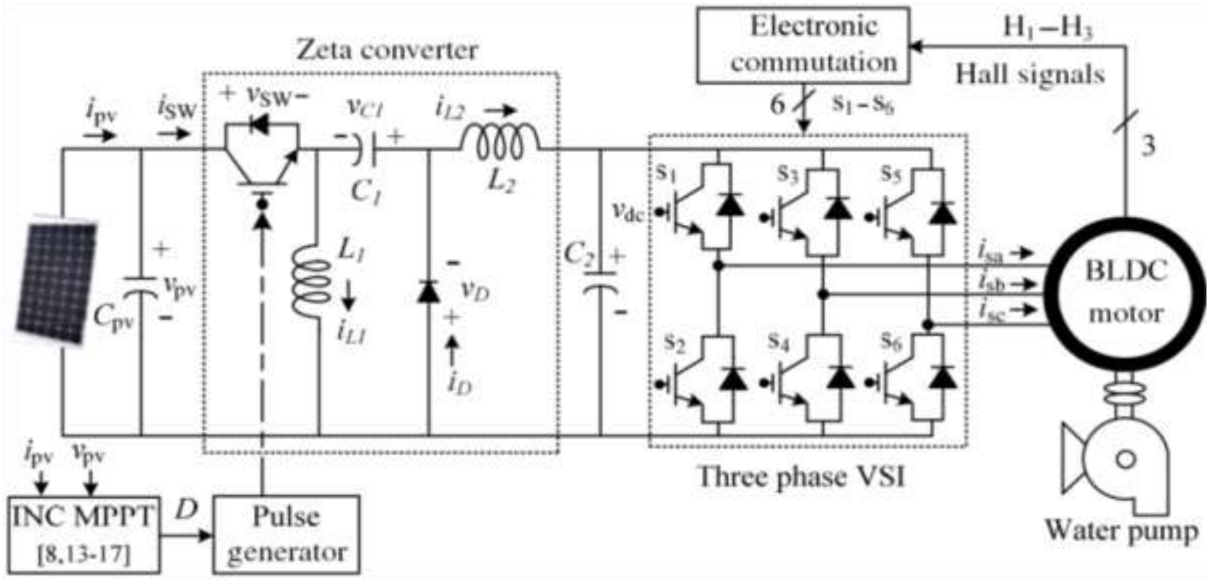


Fig. 2. Proposed SPV-zeta converter-fed BLDC motor drive for water pump.

OPERATION

The SPV array generates the electrical power demanded by the motor-pump. This electrical power is fed to the motor pump via a zeta converter and a VSI. The SPV array appears as a power source for the zeta converter as shown in Fig. 2. Ideally, the same amount of power is transferred at the output of zeta converter which appears as an input source for the VSI. In practice, due to the various losses associated with a dc– dc converter , slightly less amount of power is transferred to feed the VSI. The pulse generator generates, through INCMPPT algorithm, switching pulses for insulated gate bipolar transistor (IGBT) switch of the zeta converter. The INC-MPPT algorithm uses voltage and current as feedback from SPV array and generates an optimum value of duty cycle. Further, it generates actual switching pulse by comparing the duty cycle with a high-frequency carrier wave. In this way, the maximum power extraction and hence the efficiency optimization of the SPV array is accomplished.

The VSI, converting dc output from a zeta converter into ac, feeds the BLDC motor to drive a water pump coupled to its shaft. The VSI is operated in fundamental frequency switching through an electronic commutation of BLDC motor assisted by its built-in encoder. The high frequency switching losses are thereby eliminated, contributing in an increased efficiency of proposed water pumping system.

DESIGN

Various operating stages shown in Fig. 2 are properly designed to develop an effective water pumping system, capable of operating under uncertain conditions. A BLDC motor of 2.89-kW power rating and an SPV array of 3.4-kW peak power capacity under standard test conditions (STC) are selected to design the proposed system. The detailed designs of various stages such as SPV array, zeta converter, and water pump are described as follows.

The current of SPV array at MPP *I*mpp is estimated as

*I*mpp = *P*mpp/*V*mpp = 3400/187.2 = 18.16 A…………… (1)

The numbers of modules required to connect in series are as follows:

Ns = *V*mpp/*Vm* = 187.2/31.2 = 6…………... (2)

The numbers of modules required to connect in parallel areas follows

Np= *I*mpp/*Im*= 18.16/9.07 = 2………….. (3)

An estimation of the duty cycle *D* initiates the design of zeta converter which is estimated as

$$D = \frac{V_{dc}}{V_{dc} + V_{mpp}} = \frac{200}{200+187.2} = 0.52 \text{.............} (4)$$

Where *V*dc is an average value of output voltage of the zeta converter(dc link voltage of VSI) equal to the dc voltage rating of the BLDC motor.

An average current flowing through the dc link of the VSI *I*dc is estimated as

$$I_{dc} = p_{mpp} / V_{dc} = 3400/200 = 17A \text{....................} (5)$$

Then, *L*1, *L*2, and *C*1 are estimated as

$$L_1 = \frac{DV_{mpp}}{f_{sw}\,\Delta I_{L2}} = \frac{0.52*187.2}{20000*18.16*0.06} = 4.5*10^{-3} \approx 5mH \text{.................} (6)$$

$$L_2 = \frac{(1-D)V_{dc}}{F_{sw}\,\Delta I_{L2}} = \frac{(1-0.52)*200}{20000*17*0.06} = 4.7*10^{-3} \approx 5mH \text{....................}(7)$$

$$C_1 = \frac{DIdc}{f_{SW}\,\Delta V_{C1}} = \frac{0.52*17}{20000*200*0.1} = 22\mu F \text{....................}(8)$$

The fundamental output frequency of VSI corresponding to the rated speed of BLDC motor ω_{rated} is estimated as

$$\omega_{rated} = 2\pi f_{rated} = \frac{2\pi N_{rated} P}{120} = \frac{2\pi*3000*6}{120} = 942 \text{ rad/s.........}(9)$$

ω_{min} is estimated as

$$\omega_{min} = 2\pi f_{min} = \frac{2\pi NP}{120} = \frac{2\pi*1100*6}{120} = 345.57 \text{rad/s..................}(10)$$

The value of dc link capacitor of VSI at ω_{rated} is as follows:

$$C_{2rated} = \frac{I_{dc}}{6 * \omega_{rated} * \Delta V_{dc}} = \frac{17}{6*942*200*0.1} = 150.4\mu F \text{..........(11)}$$

Similarly, a value of dc link capacitor of VSI at ω_{min} is as follows:

$$C_{2min} = \frac{I_{dc}}{6 * \omega_{min} * \Delta V_{dc}} = \frac{17}{6*345.57*200*0.1} = 410\ \mu F \text{.........(12)}$$

Where $\Delta V dc$ is an amount of permitted ripple in voltage across dc-link capacitor $C2$.

Finally, $C2$ = 410 μF is selected to design the dc-link capacitor.

To estimate the proportionality constant K for the selected water pump, its power–speed characteristics is used as

$$K = \frac{P}{\omega_r^3} = \frac{2.89*10^3}{(2\pi*3000/60)^3} = 9.32*10^{-5} \text{............(13)}$$

Where P = 2.89 kW is rated power developed by the BLDC motor and ωr is rated mechanical speed of the rotor (3000 r/min) in rad/s. A water pump with these data is selected for proposed system.

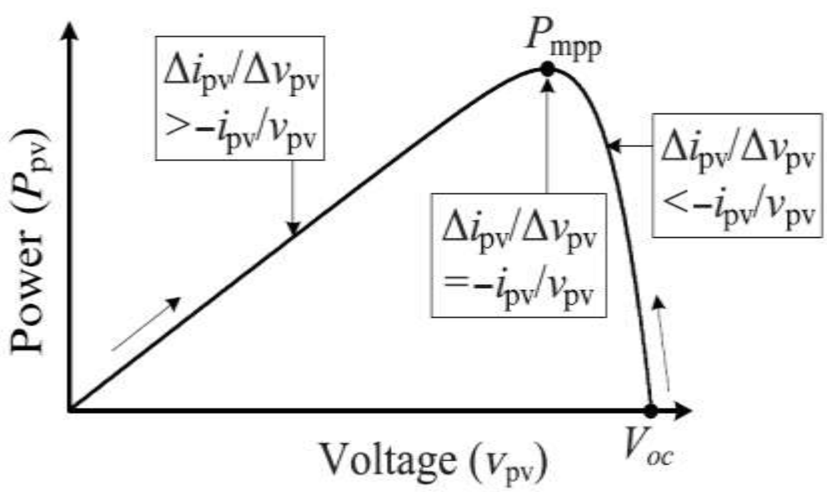


Fig. 3. Illustration of INC-MPPT with SPV array *P*pv−*V*pv characteristics.

CONTROL OF THE SYSTEM

The control of the system includes the INC-MPPT Algorithm and Electronic Commutation of BLDC Motor.

INC-MPPT Algorithm

An efficient and commonly used INC-MPPT technique], in various SPV array based applications is utilized in order to optimize the power available from a SPV array and to facilitate a soft starting of BLDC motor. This technique allows perturbation in either the SPV array voltage or the duty cycle. The former calls for a proportional-integral (PI) controller to generate a duty cycle [8] for the zeta converter, which increases the complexity. Hence, the direct duty cycle control is adapted in this work. The INC-MPPT algorithm determines the direction of perturbation based on the slope of Ppv$-V$pv curve, the slope is zero at MPP, positive on the left, and negative on the right of MPP.

Electronic Commutation of BLDC Motor

The BLDC motor is controlled using a VSI operated through an electronic commutation of BLDC motor. An electronic commutation of BLDC motor stands for commutating the currents flowing through its windings in a predefined sequence using decoder logic. It symmetrically places the dc input current at the centre of each phase voltage for 120◦. Six switching pulses are generated as per the various possible combinations of three Hall-effect signals. perceptible that only two switches conduct at a time, resulting in 120◦conduction mode of operation of VSI and hence the reduced conduction losses. Besides this, the electronic commutation provides fundamental frequency switching of the VSI; hence, losses associated with high-frequency PWM switching are eliminated. A motor power company make BLDC motor with inbuilt encoder is selected for proposed system.

IV.CONCLUSION

This project presents a new method for water pumping modes. The proposed maximum power tracking of solar employing zeta converter method in our project is an improvement over the existing method due to the fact that it does not require non-renewable energies for operation. This allows for PV array to continuously supply power to the system without having to shut down.

Due to the difficulty of coupling the BLDC to pump in the prototype, we decided to use output analysis of the BLDC to compare against mechanical input of a pump. We simulate the prototype under the maximum power input mode using MATLAB.

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